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DEVELOPMENT OF A PROCESS FOR PNEUMATIC EXTRUSION OF METALS

FIRST QUARTERLY REPORT

BY

L.A. FINLAYSON

APRIL 1966

IIT RESEARCH INSTITUTE
TECHNOLOGY CENTER
CHICAGO, ILLINOIS 60616

CONTRACT DA-19-066-AMC-307(X)

U. S. ARMY MATERIALS RESEARCH AGENCY
WATERTOWN, MASSACHUSETTS 02172

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ABSTRACT

This first quarterly report contains the results obtained extruding metals using both fluid and gas pressure medium on a small scale unit. Also included are the designs of the large scale unit now being constructed. A technical discussion is presented on the sealing required between die and billet and also the ram seal.

The progress and the project schedule for the remainder of the project are discussed.

FOREWORD

This report on IIT Research Institute Project No. M6136 covers the work performed November 19, 1965 through March 15, 1966, on Contract No. DA19-066-AMC-307(X). This contract is funded under the U.S. Army Manufacturing Methods and Technology Program and is technically supervised by Mr. S V. Arnold of the United States Army Materials Research Agency.

Major responsibility for technical direction of the program resides with Mr. L.A. Finlayson. Significant contributors to the program during the current reporting period include H. Lane, E. Wiegand, R.J. Wolf, and M.H. Zoiss

Respectfully submitted,

IIT RESEARCH INSTITUTE

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LAF/lb

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INTRODUCTION

The production of extruded structural shapes and tubes of very high strength and refractory alloys puts some very stringent requirements on extrusion containers, extrusion dies and extrusion lubricants. Some of these problems have been solved; the solutions to others are under study. However, the inherent problems in the extension of conventional extrusion techniques to high temperatures and pressures have prompted the exploration of alternative techniques ranging from the use of Dynapak techniques to the use of super-high hydrostatic pressures. This program will delineate a new approach to the extrusion problem, namely pneumatic extrusion, wherein we will seek to combine the tooling of low temperature hydrostatic extrusion with the use of the high temperatures employed in conventional extrusion.

There are several approaches to combined high temperature-hydrostatic extrusion; the two most promising are the (1) the use of a hot billet in a liquid metal and (2) the use of a hot billet in a gas pressure system. The former approach suffers from some very real problems with heat loss from the pre-heated billet into the container and auxiliary tooling as well as process flexibility restrictions arising from high temperature reactions between the container wall material, molten metal and molten metal billet. In the gas system most of these obvious faults are eliminated. The use of an inert gas reduces the reactivity problem, cuts the heat transfer to the container and provudes for a mechanical cushion between the extrusion and the stem. The pneumatic system is identical in basic configuration to hydrostatic systems with exceptions in detail only.

When operational, a pneumatic extrusion system will offer the same advantages as those inherent in hydrostatic extrusion with one very important exception. In pneumatic extrusion, it will be possible to use quite high temperature billets and thus reduce substantially the pressure requirements. For instance the use of 2,000 to 2500°F billet temperatures would reduce the chamber pressure requirements to the 150 to 180,000 psi range for most of the material systems of interest. These pressure requirements are within the range of current container technology and hence will facilitate the timely translation of this new technology into production.

SECTION II

FULL SCALE PNEUMATIC EXTRUSION UNIT

This section contains the final designs for the extrusion unit and its support equipment. The drawings are not completely detailed in this report. Shop drawings have been prepared and the components are in progress. Final system and component drawings will be supplied at the end of the program.

A. BASIC EXTRUSION UNIT DESIGN

Figure 1 shows the basic unit as it is being built. Briefly, it is comprised of a 16 in. bore, 20,000 psi pressure vessel tied to a 3 in. bore, 150,000 psi pressure vessel. A stepped piston (actually several pieces) provides the force required to generate the high gas pressure in the 3 in. bore. The 20.4:1. ratio intensification begins with low pressure oil in the 16 in. bore section.

For the purposes of this report it should be mentioned that the 16 and 3 in. vessels are the property of IITRI. The 3 in., 150,000 psi vessel is actually a 4 in. vessel which is being provided with a sleeve to protect the bore. Damage to the bore could result in the event that during a gas extrusion a pressure seal fails and the ram engages the billet with sufficient force to deform it radially into the chamber wall.

Components of the unit are described as follows:

1. Low pressure seals use "0" rings with backup rings. The 16 in. piston also has "0" rings for seals. It also carries a bearing plate to distribute the force of the 3 in. piston.

2. Between the low and high pressure chambers is a spacer block which will carry an alignment bushing. This serves several purposes: a low pressure oil seal; an inlet for precharging the 3 in. bore with pneumatic pressure and as an alignment bearing.

3. The main 3 in. ram is sealed with an "0" ring - backup ring. Built into the main ram is an inner ram which will be used to preseat the billet in the die. During the time that the main ram is moving forward, the inner ram will retract under pressure and a Bridgman seal will then provide the inner ram seal.

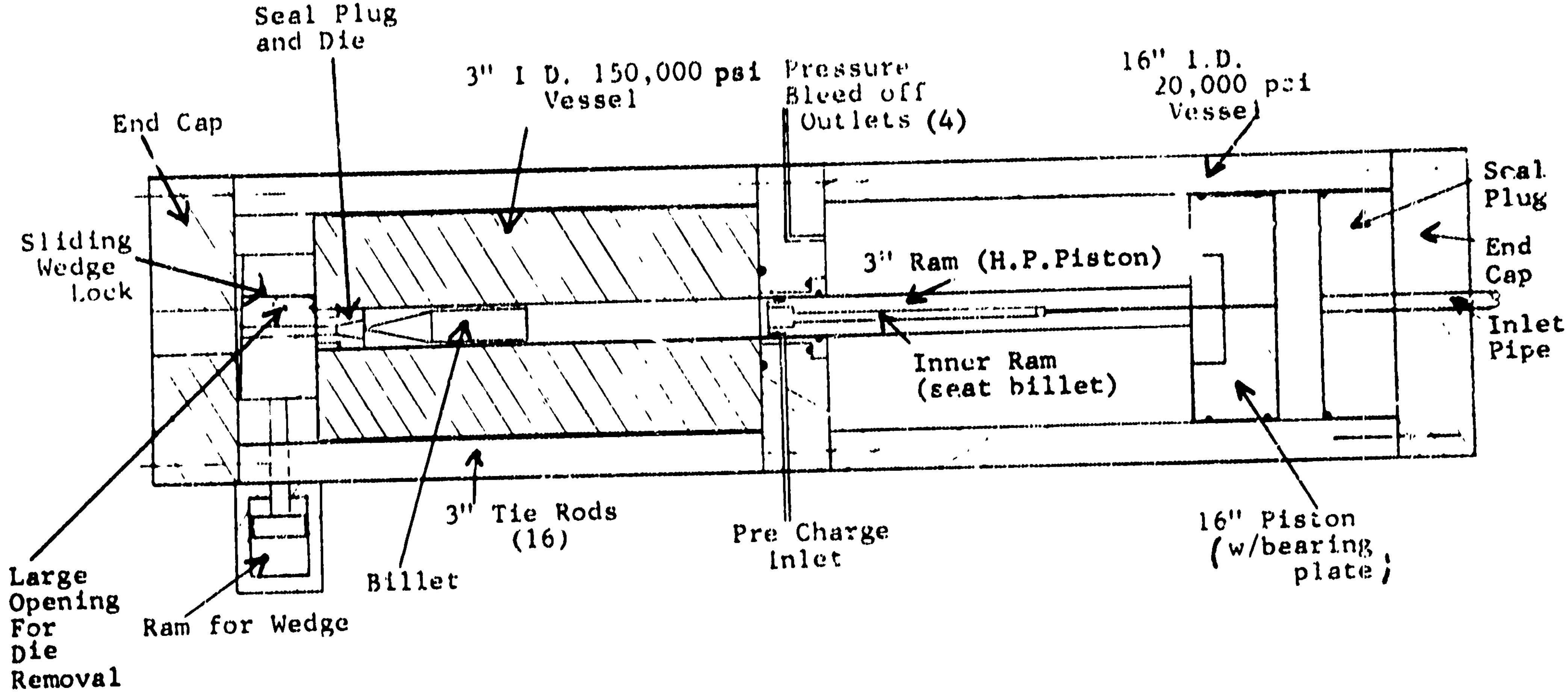


Fig. 1 BASIC PNEUMATIC CUSHION EXTRUSION CHAMBER DETAIL

4. The die and seal plug are a Bridgman type. The die section acts as the mushroom and is designed as a replaceable part. The die and seal plug are held in place by a sliding wedge block system. This provides for a fast handling system.

5. The entire system is tied together by the tie bars which with a large end plate on the end will lock in the 3 in. chamber.

B. OVERALL SYSTEM DESIGN AND OPERATION

Five 16 in. navy gun projectiles are used to store the volume of gas and fluid required to stroke the system. The calculations of available gas volumes are contained in Section II C. Figure 2 shows the basic unit with the 16 in. projectiles and the auxiliary piping, valves and pumps. Operation of the system proceeds as follows using Fig. 2 as a reference. The five 16 in. projectiles (referred to as accumulators) are filled with gas and liquid at 22,000 psi, see Section II C for procedure and calculations.

Operations begin with a billet in place and only partially seated. The high pressure chamber is closed and all valves are closed except the individual valves which tie each projectile to the manifold and the accumulator dump valve.

At this point valves 7 and 8 are opened and the right side of the 16 in. piston is charged with approximately 15,000 psi. This pressure is supplied by direct pumping and not from the accumulators. Valves 7 and 8 are closed. Valve 2 is opened and pressure is brought up to 15,000 psi and then valve 2 is closed. This activates the inner ram to seat the billet. Valve 1 is then opened. The gas pressure is brought up to 20,000 psi. This will cause the inner ram to retract. Valve 1 is then closed. Valve 2 is opened and at the same time valves 3 through 6 are opened. As the pressure on the right side of the 16 in. piston drops the piston begins to advance. The rate of advance is controlled by the number of valves (3 through 6) that are opened.

After extrusion has started, valve 9 is opened to vent the volume between the stationary and moving ram seals. During the actual extrusion, closing of valves 3 through 6 causes the pressures on both sides of the 16 in. piston to equalize. Depending on the extrusion, pressure relationships and the remaining billet volume, this procedure can cause extrusion to be stopped at a predetermined point.

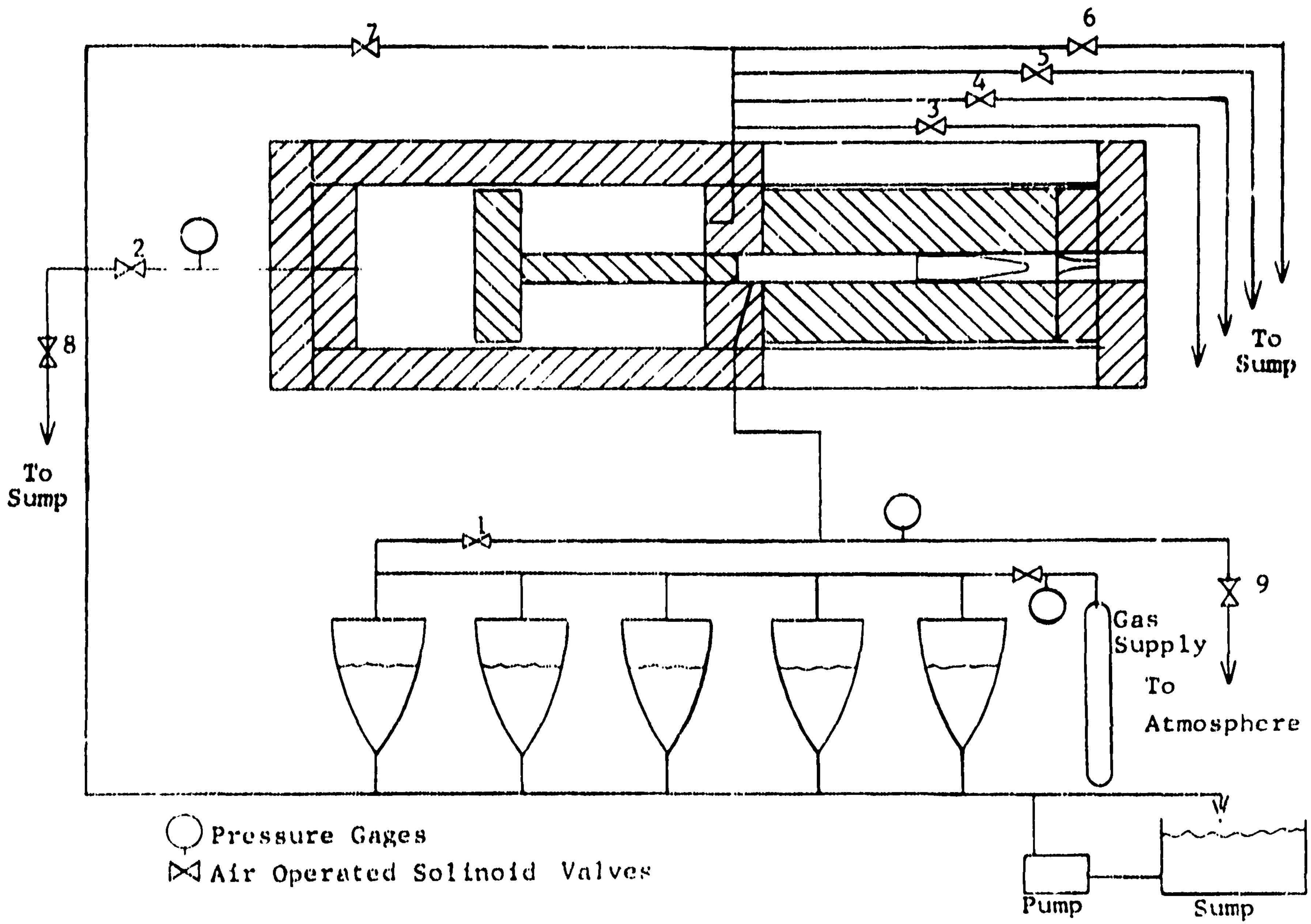
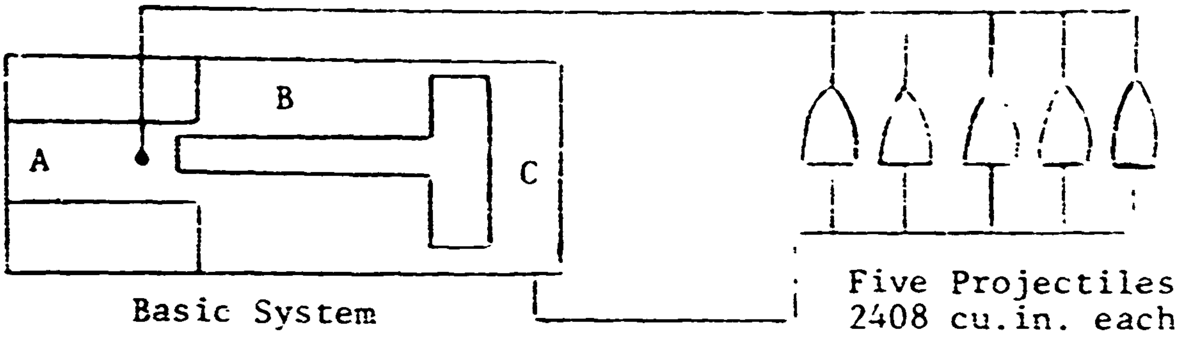


Fig. 2 LAYOUT OF THE BASIC EXTRUSION UNIT WITH ITS SUPPCRT EQUIPMENT

C. GAS VOLUMETRIC CALCULATIONS FOR PRECHARGING AND EXTRUSION OPERATION



Vol A: 3 in. diameter x 23 in. long = 163 cu. in.

Using the available 3,000 psi gas compressor, operation proceeds as follows:

1. Fill all five projectiles with 3,000 psi air and pump the first four up to 15,000 psi letting the gas all go into the fifth cylinder.

Results: 12,040 cu. in. gas in number 5 at 15,000 psi.

2. Fill the first four again with 3,000 psi air and pump the first three up to 12,000 psi letting the gas all go into the fourth cylinder.

Results: 9,632 cu. in. gas in number 4 at 12,000 psi.

3. Fill the first three again with 3,000 psi air and pump the first three up to 22,500 psi letting the gas all go into the fourth and fifth cylinder again.

Results: 36,320 cu.in. of gas in numbers 4 and 5 at 22,500 psi, Numbers 1,2 and 3 are full of liquid at 22,500 psi.

Open appropriate valves to let the gas and liquid equalize and let liquid level equalize. Now there is at 22,500 psi stored:

7,625 cu. in. of liquid
4,415 cu. in. of gas.

Referring to diagram, Volume B is pumped to 20,000 psi directly from pump. Volume C = 0 psi.

Fill Volume A with gas from five projectiles.

$$4,415 \times 22,500 = (4,415 + 163)\ P$$

$$P = \frac{4,415 \times 22,500}{4578}$$

New pressure in projectile is P = 21,699 psi

A = 21,700 psi B = 20,000 psi C = 0

After stroking 33 in. on 16 in. piston the remaining stored pressure is 6,635 = vol. 16 in. cylinder at 33in. stroke.

$$4,415 \times 21,699 = P\ (4,415 + 6,635)$$

$$P = \frac{4,415 \times 21,700}{11,050} = 8,670 \text{ psi}$$

Pressure required for 150,000 psi gas pressure is ratio 3 in. cylinder to 16 in. cylinder.

$$150,000 \text{ psi} \times 7.068 = P \times 201.06$$

$$P = 5274 \text{ psi}$$

As can be seen there is a sufficient volume of gas and oil to precharge to 20,000 psi and to stroke the large piston and still have sufficient pressure for generating 150,000 psi after a 33 in. stroke. This extra amount will cover friction forces not considered in the 28.4:1 ratio of pressure generating. It will also cover an extra precharge in the event of a bad seat between billet and die.

For simplicity, all calculations here are based on isentropic expansion.

SECTION III

SMALL SCALE PNEUMATIC EXTRUSION UNIT

In order to assess immediately the feasibility and operational problem of pneumatic extrusion, we have used a small scale unit to quickly arrive at answers to the immediate problems and to provide a test stand for systems changed in the larger unit. Since all equipment was readily available for such an effort, we assembled a 3/4 inch bore 150,000 psi system and had billets machined. A new closure seal plug-die combination was constructed. The plug-die was the only part necessary to modify our existing equipment to do extrusion.

A. DESCRIPTION OF THE SMALL SCALE SYSTEM

Figure 3 shows the system and its components. Figure 4 shows a view of the seal plug-die combination and the type of specimens used. Specimens were lightly coated with ordinary bearing grease and inserted into the die. The thread on the end allowed the billet to be pulled lightly against the die face to start an initial seal between the die and billet.

To extrude using liquid, the specimen and seal plug-die were placed into the vessel which had been filled with water. After the vessel was closed, the ram on the press was raised forcing the piston upward to generate pressure. The vessel was clamped in the press holding it in position.

When the extrusion was forcefully extruded, it was projected upward into a catcher on the top of the press. For this application we used a cylindrical steel can filled with layers of cardboard. All of the specimens were twisted badly, due to the impact.

In order to extrude using gas, the same procedure was used except that the system was precharged to 2,000 psi with dry nitrogen. A 6-1/2 in. bore vessel was used as a gas to liquid accumulator. It was also precharged with 2,000 psi nitrogen and filled with liquid until the gas pressure reached 20,000 psi. The vessel was then isolated from the extrusion unit, and the press ram was raised to increase the pressure required to cause extrusion.

B. RESULTS OBTAINED FROM THE SMALL SCALE EXTRUSION UNIT

Specimens were prepared from 1100 Al and machined. In order to expedite operations, the same conical die was used for all extrusions and the billet size was varied to give the reported degrees of deformation. After machining, the Al specimens were annealed at 650°F.

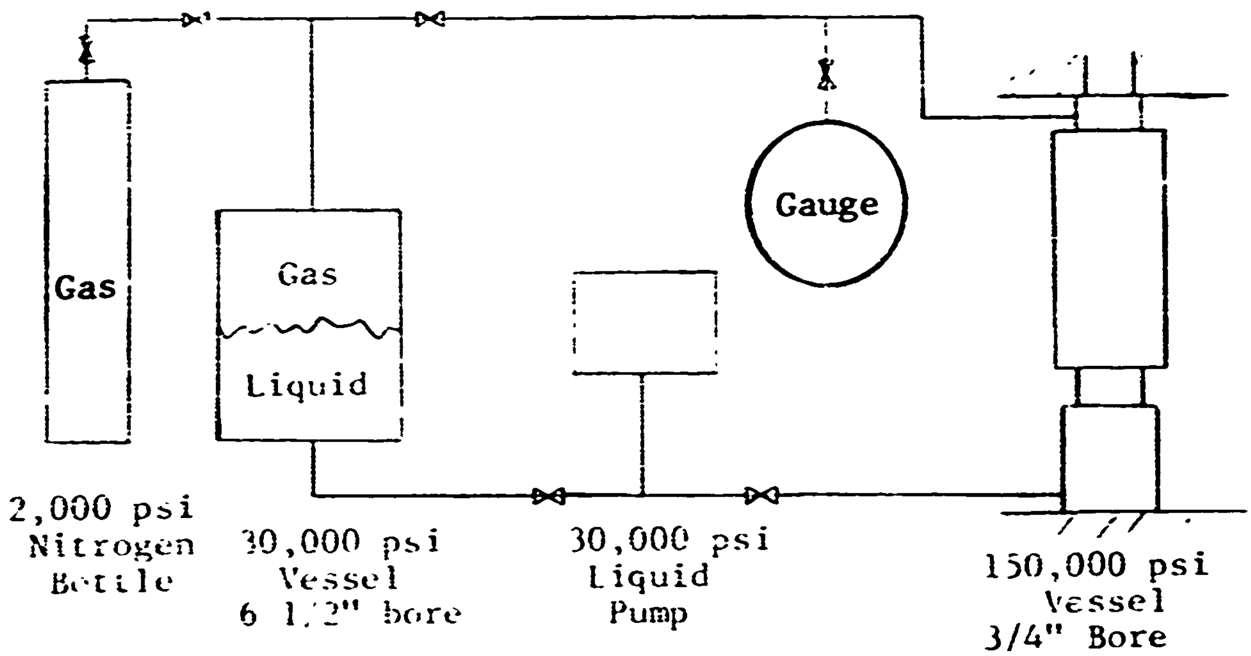


Fig. 3 SCHEMATIC DIAGRAM FOR SMALL SCALE LIQUID AND PNEUMATIC EXTRUSION APPARATUS

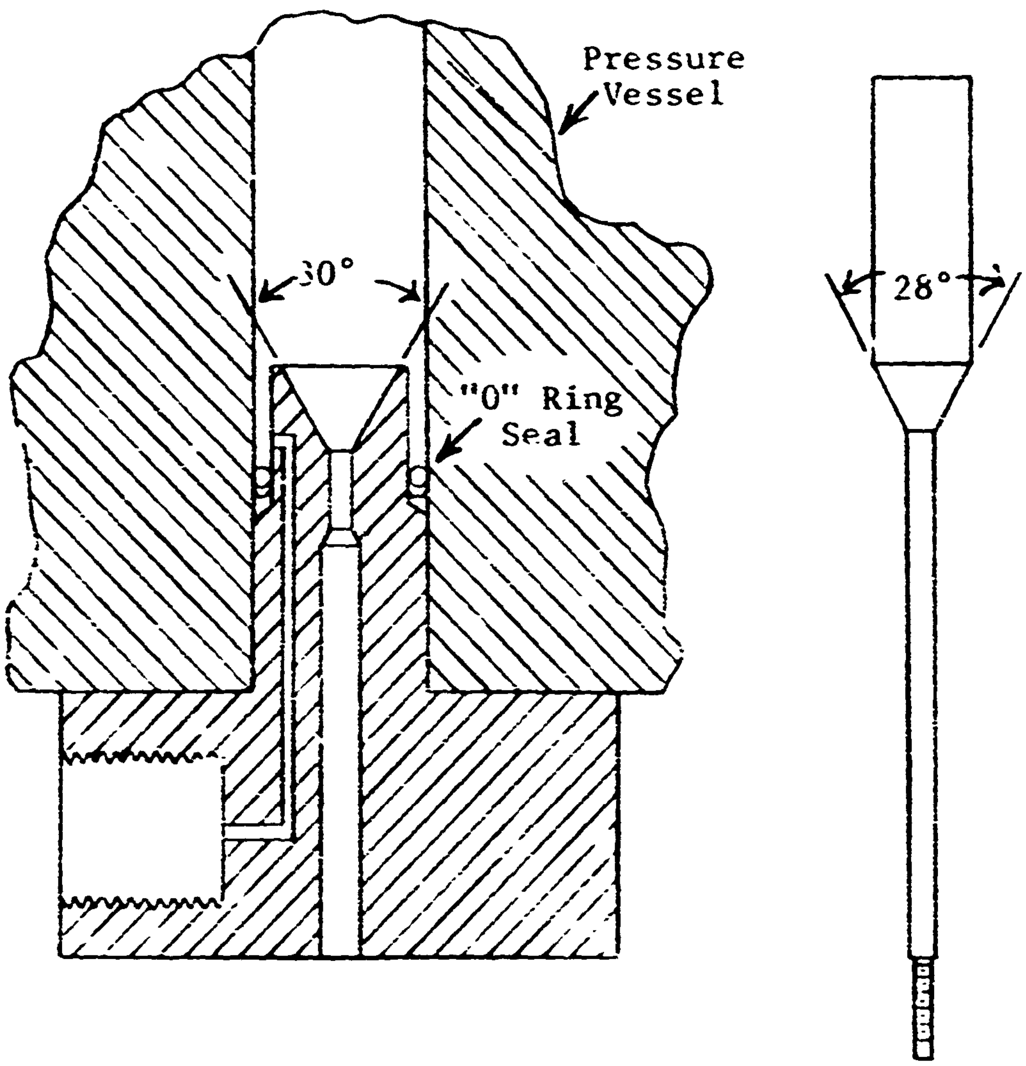


Fig. 4 EXTRUSION DIE AND BILLET

Table I shows the different sizes of specimens run and also the extrusion pressures required. Also listed is the area of reduction, which may be more familiar to some investigators. Degree of deformation is defined as ψ

$$\psi = \frac{F - f}{F}$$

F = area before extrusion

f = area after extrusion

Figure 5 shows the two curves arrived at using liquid and gas extrusions. It is our tentative conclusion, based on a limited number of extrusions, that above a certain value there will be very little or no difference in the mechanism of gas or fluid extrusion. At the lower pressures, (e.g. below 75,000 psi), there is a difference, as the gas pressures are higher than the liquid pressures. There are several explanations for this, but a cursory examination reveals that these lower ratio extensions show a lack of hydrodynamic lubrication. Several other extrusions were done on C1018 steel and Al alloy. However, not enough were done to permit a comparison of data.

One point which has been encouraging is that after a total of 17 extrusions, the die is still in its original condition. The material used for the die was Vasco Max 300 (Maraging Steel) aged to give a hardness of Rc55.

Table I

DATA FOR LIQUID AND PNEUMATIC EXTRUSIONS*

Specimen No.	Pre-Extrusion Diameter (in)	Extrusion Ratio	Degree of Deformation	Extrusion Pressure Liquid (psi)	Extrusion Pressure Gas (psi)
1	0.187	1.44	0.290	15,000	--
1A	0.187	1.44	0.290	17,000	38,000
2	0.210	1.82	0.450	21,500	--
2A	0.210	1.82	0.450	33,000	43,500
3	0.250	2.56	0.600	42,500	61,000
4	0.312	4.00	0.750	55,000	54,500
5	0.500	10.00	0.900	78,000	81,000

* All extrusions were with 1100 aluminum fully annealed.

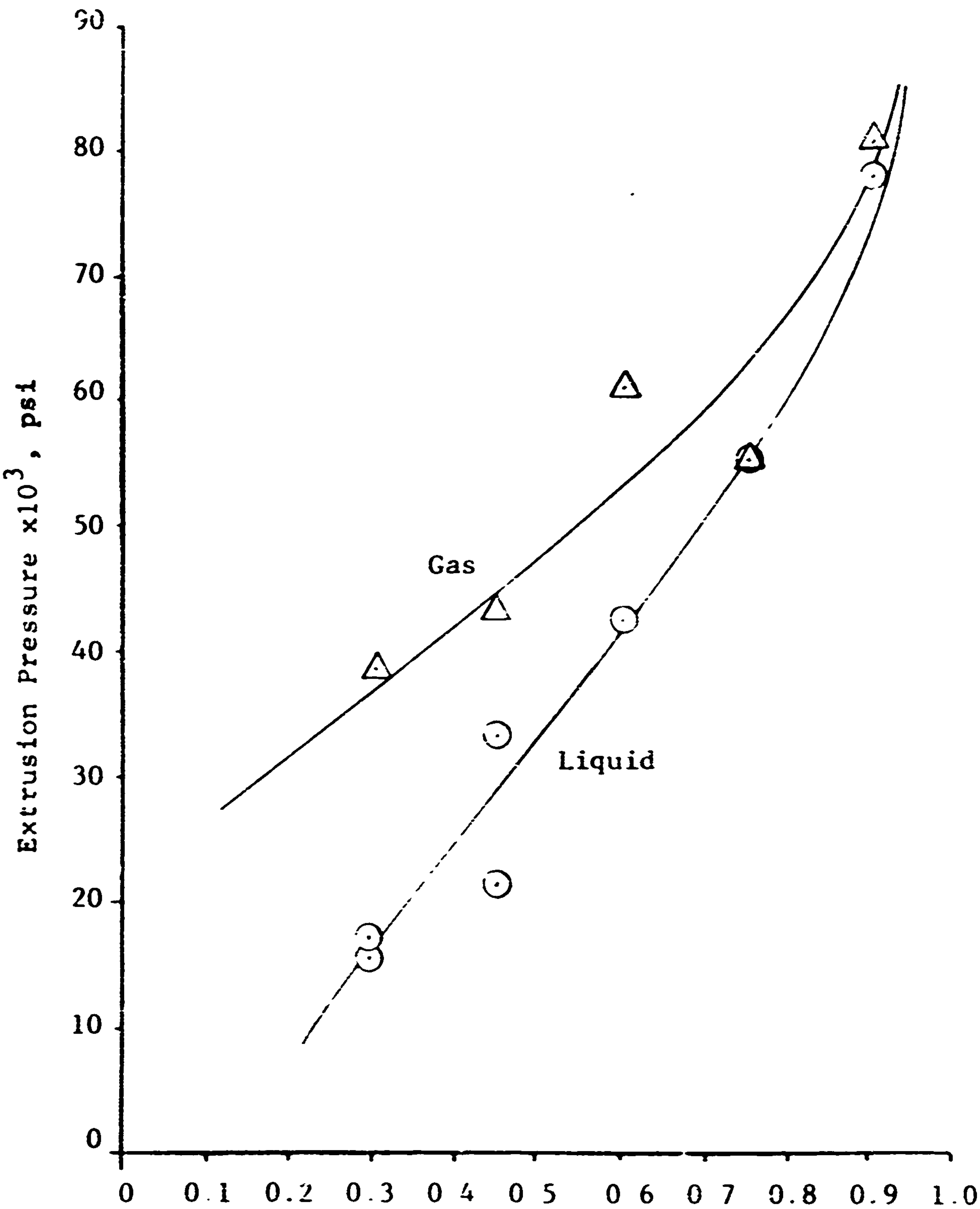


Fig. 5 DEGREE OF DEFORMATION

SECTION IV

TECHNICAL DISCUSSION

A. FEASIBILITY DEMONSTRATION

One of the phases of this program was to determine the feasibility of pneumatic extrusion. Since this has not been done to our knowledge, there exists a basic question as to whether material will extrude through a die in a similar manner to that in fluid extrusion. The opinion has been expressed that this type of extrusion would be more like a mechanical extrusion as far as the billet and die were concerned.

The purpose of the small scale extrusion system (already described in this report) was to compare the extrusion pressures versus degree of deformation values for fluid extrusion and the same values for gas extrusion. The results, Fig. 5, show the values that were found by extruding twelve specimens (seven with liquid and five with gas). These curves seem to show that above a value of approximately 75,000 psi the extrusion takes place at the same pressure regardless whether it is liquid or gas. Below this value the gas curve is higher. Evidently the gas is not dense enough to properly form a film between the billet and die. (Such film was not expected).

It must be pointed out that the reported data is preliminary and with many variables entering into the picture. No attempt was made to select the proper lubricant for gas and liquid work, but rather the same lubricant was used on both to maintain a common basis for comparison. All billets were machined to a fine tool finish. The die itself was machine tool finished and hand polished with crocus cloth on a lathe. The bearing section of the die was reamed out with a standard reamer. Due to the two degree difference on the billet and die angle, some work hardening was produced as the initial deformation took place. This had an effect on the extrusion pressure. It was noted that, the faster pressure was generated, the lower the extrusion pressure was for the same degree of deformation.

While our results show the two curves for 1100 Aluminum, some Al alloy and C1018 steel specimens were extruded. Our values for fluid extrusion are in agreement with the USSR work of Vereschogin*.

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* Vereschogin et al, Some Problems of Large Plastic Deformation Pergamon Press, 1963.

B. PRESSURE SEAL BETWEEN BILLET AND DIE

Contrary to preliminary concerns, the problem of sealing between the billet and die does not appear to be a difficult one. Our efforts on the small scale unit gave no trouble whatsoever. Initially the billets were machined with a two degree difference in cone angle from that of the die approach. As soon as pressure was generated, a positive seal was obtained. In several cases where the billet was deformed to fit the die, it was removed and then replaced. With no difference in angle, the seal was still obtained. Since the specimens were not particularly hard, it is possible that harder materials will present some trouble. The main extrusion unit contains an inner ram on the main ram. The purpose of this is to seat the billet and form such a seal. This ram should not be necessary for the softer materials. However, provisions will be made for this inner ram in the event harder materials require this seating force.

It is also significant that suitably backed "O" ring seals appeared to be of a soft material satisfactory for both static and dynamic gas seals. The Bridgman seals used were also quite satisfactory. We were able to hold precharge pressure overnight without leakage. These seals may cause some problems as we scale up to the 3 in. bore chamber. However, the body of experience with large bore liquid seals should be sufficient to overcome the more obvious of the problems.

SECTION V

STATUS OF DESIGN AND CONSTRUCTION

As of this writing the following has been accomplished in the design and construction of the large extrusion device and support equipment.

Main H.P. Chamber - The material is now on hand to machine a sleeve for installing into the bore.

Main L.P Chamber - Has been bored and is ready for assembly.

End plates, plugs etc. - These have been designed and are awaiting machining. Materials are stock items.

Projectiles with stands (gas pressure storage) - Minor modifications have been completed and these are being setup.

A safety wall which isolates the main extruding device from the projectiles and also isolates both of these from the operators has been completed.

Section VI in this report sets forth a milestone plan showing the sequence of performance for the remaining phases of the program.

SECTION VI

PROGRAM PLAN

Figure 6 is a bar graph that demonstrates what efforts are planned and to what schedule.

As our efforts on the 3/4 in. bore vessel were quite successful with minimum expenditure of time and money, it is anticipated that we will continue the use of this small chamber to check out design changes on a small scale. One design change which will be well suited for scaled down studies will be the extrusion catcher.

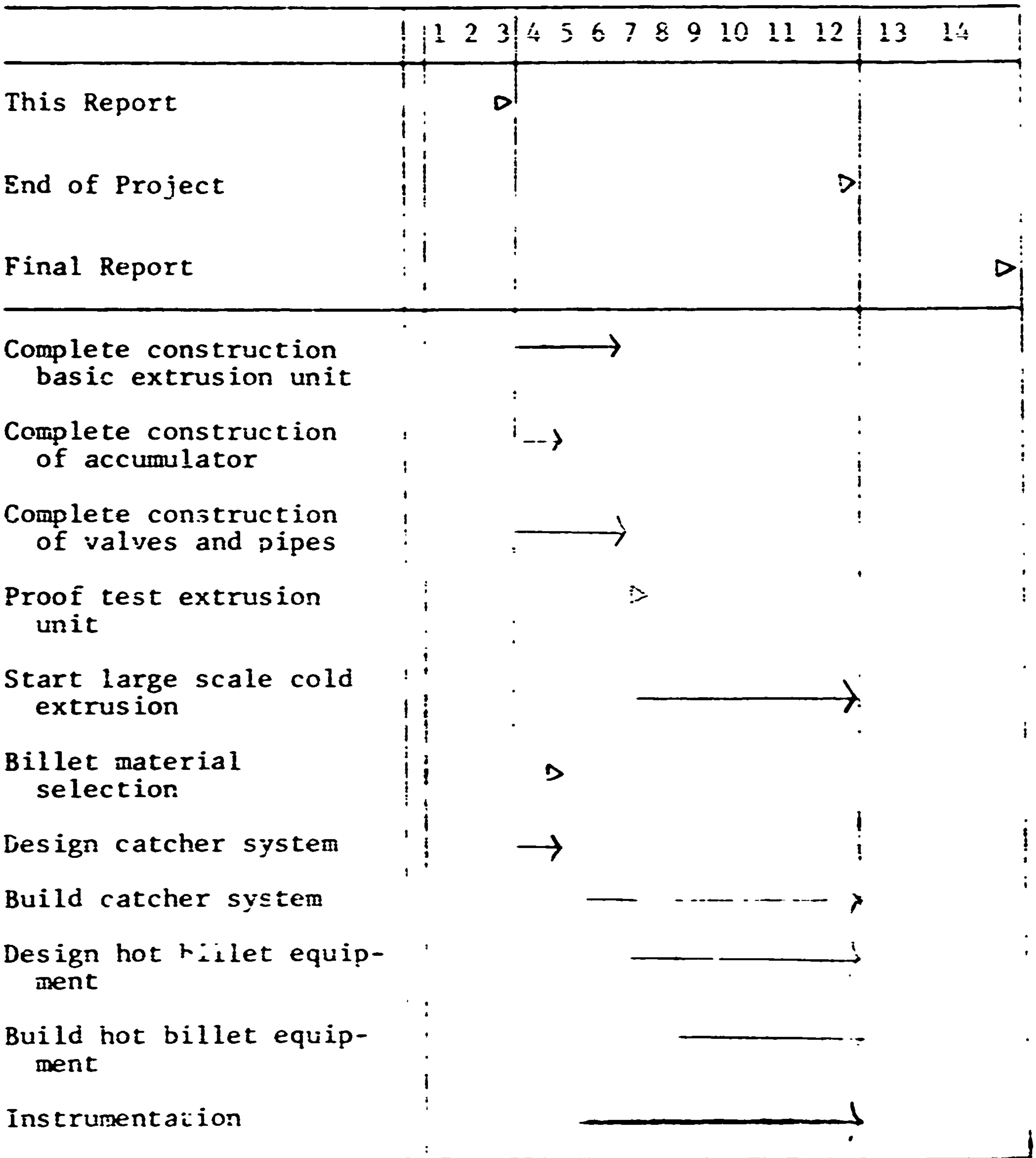

Fig. 6 PROGRAM SCHEDULE

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